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Velocity of Detonation and Charge Diameter in some RDX-Driven Heterogenous Explosives: PBXW-115, PBXN-111, H-6 and Composition B

D.J. Whelan, R. Swinton
and G. Bocksteiner

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Weapons Systems Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Experimental data on the dependence of velocity of detonation on charge diameter, V(d), of unconfined cylindrical charges of the underwater explosives, PBXW-115 (Aust.), PBXN-111 and Composition H-6, and of Composition B, the explosive charge fill offered by Nordic Defence Industries for the Danish Mine Disposal Charge, Damdic, are given. These data are analysed in terms of the previously-reported empirical relationship between the V(d), the detonation velocity at infinite charge diameter (D*) and the reaction zone length parameter, (a*).

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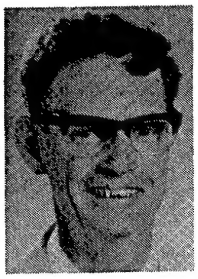
Executive Summary

In 1994, the Directorate in charge of the Mine Hunter Coastal Program opted to acquire the Bofors-Sutec Double Eagle Remotely-operated Mine Demolition Vehicle and to equip it with the small, Danish Mine Disposal Charge warhead rather than the standard, larger NATO warhead. This smaller warhead, dubbed the Damdic warhead, contains approx. 35 kg high explosive (HE) and was offered with a Composition B fill. The NATO warhead, as used in the French - made PAP Remotely-operated Vehicle, contains approx. 100 kg HE, and is usually filled with a torpex-type fill.

For several years, Weapons Systems Division, AMRL has been working with the Directorate of Armament Engineering - Navy, developing a polymer bonded explosive which could be manufactured in Australia by Australian Defence Industries, and evaluating data on underwater explosives, in general. This program has resulted in the formulation and characterisation of PBXW-115 (Aust.), an explosive fill which has been passed by the Australian Ordnance Council in the context of PBXW-115 conforming to the Council's guidelines for Insensitive Munitions and having superior underwater performance. As an extension of this work, PBXW-115 (Aust.) is currently undergoing large scale qualification testing in a Damdic warhead with the intention of introducing it into service.

In this paper, experimental data on the effect of charge diameter on the velocity of detonation of unconfined PBXW-115 (Aust.) and of its US counterpart, PBXN-111 is given, alongside that of the torpex-like fill, Composition H-6, and the Danish offering, Composition B. The data has been analysed in terms of a mathematical relationship, identified by AMRL in 1993/94, and - from that analysis - an estimate of a reaction zone length parameter for each detonating explosive can be deduced as well as an estimate of its failure diameter. These data can be used to design effective warheads with an optimal geometry.

Authors



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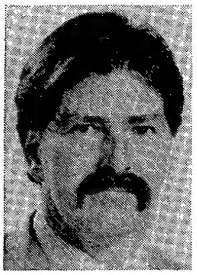
Dan Whelan joined AMRL in 1968 and worked in various areas of Organic Chemistry Division before transferring to the forerunner of Explosives Ordnance Division in 1980. His current interests are in explosives performance, underwater explosives, thermal analysis, solid state reaction kinetics and practical data correlations. He is on the Editorial Board of the Journal of Energetic Materials.



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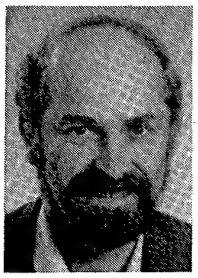

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Gunter Bocksteiner graduated from Footscray Institute of Technology in Applied Chemistry and joined AMRL in 1968. He has worked widely within AMRL, initially on the mechanistic chemistry of chemiluminescent materials, then biologically active surface coatings and the effects of the marine environment on defence materiel. In 1980 he commenced work on determination of explosives hazard, and since 1987 has been working on polymer bonded explosives formulations.

Contents

1. Introduction

Whelan and Bocksteiner [1,2] have recently reviewed the status of the various mathematical relationships between the experimentally-observed steady-state velocity of detonation (V of D or V(d)) and charge diameter (d) for cylindrically-shaped, unconfined RDX-driven composite explosives. They have suggested that, for many of these formulations, the relationship between V of D and d follows not the familiar linear, Eyring relationship [3],

$$V(d) = D\,(1-[\,a / d\,]) \qquad \text{(Eq. 1)},$$

where D and a are also curve fitting constants, or linear variations of it [4] but rather an elliptical dependence of the form

$$V(d)^2 = (D^*)^2\,(1-[\,a^* / d\,]^2) \qquad \text{Eq. 2)},$$

where D* and a* are curve fitting constants.

This conclusion was reached not only by considering the linear least squares analyses of experimentally-determined data from several formulations [1, 2] but also, in almost every case, by noting that the experimental values of V(d) for large diameter charges were appreciably less than those expected on the basis of Eq. 1.

It was also observed that there appears to be a simple connection between the critical diameter, d_c, and a*, viz.,

$$d_c = 2.208\,a^* \qquad \text{(Eq. 3)}.$$

Here, a* could be regarded as a reaction zone length parameter characteristic of the formulation in the same way that Wood and Kirkwood [5] have related the CJ-point of a detonation, ξ^*, to the radius of curvature, S, of the detonation wave front.

Those formulations whose V(d) profiles appeared to follow Eq. 2 all appeared to have a significant component of coarser (perhaps > 150 μm) particle sized RDX in their formulation, whereas those which appear to follow Eq. 2 more closely, behaved more like typical monomolecular explosives and contain considerable fine (perhaps < 50 μm) RDX [1, 2, 6].

In this paper, the authors present a selection of the actual experimental data upon which this relationship was arrived at, for the underwater explosives, PBXW-115 (Aust.) [1,2], its US counterpart, PBXN-111 [1,2,7], and the High Blast Explosive, Composition H-6 [8], and the widely-used explosive, Composition B [,9]. Some of these data were summarised in the earlier report [1] without the supporting experimental data.

2. Formulations

PBXW-115 (Aust.) and PBXN-111 are described in detail elsewhere [1,2]. Both are cast-cured PBXs, made from bimodal RDX (20 %), ammonium perchlorate (AP) (43 %), Al (25 %) in a plasticised HTPB-based polyurethane binder (8 %). The principal differences between the two formulations are in the coarser RDX component of the formulation. *Woolwich (Nitric Acid Process) or Type I RDX* [10] makes up the coarser RDX component in PBXW-115 (Aust.); this type of RDX is HMX-free [2]. On the other hand, *Bachman (Acetic Anhydride Process) or Type II RDX* [11] makes up the coarser RDX component in the bimodal mix used for PBXN-111 and this type of RDX typically contains from 4 to 14 % HMX [2].

The formulation, Composition H-6, upon which the reported experimental data is based [12 a], was made at AMRL to US Military Specification MIL-E-22267A using RDX [Type I, Grade 1] of Australian manufacture. This batch of Composition H-6 analysed within specification [12 b] to TNT 27.7 %, RDX 43.1 %, Al 22.7 %, $CaCl_2$ 0.4 %, Wax 6.1 %.

In the following discussion, the authors will be referring to V (d) data on Composition B, tabulated by Gibbs and Popolato [9]. It is assumed that the formulation of this Composition B was made to US Military Specification MIL-C-401E (13 Mar 1974), from RDX [Type II Class 1] 59.5%, TNT 39.5%, Wax 1%.

RDX (Class 1) produced to US specifications [11] has the following particle size distribution: particle size greater than 300 μm - 10 % (max.), particle size between 300 and 75 μm - at least 65 %, and particle size less than 75 μm - 25 % (max.). On the other hand, RDX (Grade 1) produced to Australian specifications [10] has a slightly different particle size distribution: particle size greater than 300 μm - 25 % (max.), particle size between 300 and 75 μm - not less than 67 %, and particle size less than 75 μm - 12 % (max.).

3. Experimental Results

In Tables 1-4, the V(d) data for unconfined cylindrical charges of PBXW-115 (Aust.) [1,2], PBXN-111 (also known as PBXW-115, from the US Naval Surface Warfare Center) [7], Composition H-6 [8] and Composition B [4,9] are listed, while in Table 5, an analysis of these data is given. The data for Composition B is also produced graphically in Figures 1 and 2. Similar plots can be drawn for the other compositions. From these plots for Composition B it is apparent that, overall, there is less scatter in Figure 2 than in Figure 1 and that at larger diameters, the data fit Eq. 2 more closely than they fit Eq. 1 (Table 5).

Table 1. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of PBXW-115 (Aust.), density 1.79 Mg m^{-3} [Ref. 2].

Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}
200	5557	110	5306
170	5525	110	5372
140	5476	80	5072
140	5445	80	Fail

Table 2. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of PBXN-111, formerly known as PBXW-115 from NSWC, density 1.79 Mg m^{-3} [Ref. 7].

Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}
69.1	5540	49.6	5421
49.9	5315	41.1	5190
49.7	5331	38.7	5036
49.6	5365	35.5	Fail

Table 3. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of Composition H-6, density 1.74 Mg m^{-3} [Refs. 2, 8].

Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}
38	7355	13.47	7294
22.75	7348	13.47	7290
22.75	7325	9.4	7238
15.7	7283	9.4	7147
15.7	7330		

Table 4. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of Composition B, density 1.70 Mg m^{-3} [Ref. 4].

Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}
25.5	7868	12.7	7819	7.95	7738
25.5	7889	10.0	7787	7.95	7725
24.8	7869	10.0	7792	7.96	7746
24.8	7864	10.0	7755	6.36	7648
24.8	7847	8.48	7738	6.35	7650
12.7	7816	8.47	7742	5.61	7572

Table 5. Analytical Description of the Relationship between the observed V of D and Charge Diameter for Unconfined Cylindrical Charges of PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B.

PBXW-115 (Aust.) : Unconfined Charges, Charge Diameters: 80 mm to 200 mm.
Critical diameter: 80 mm (1x Go, 1x No-Go)
$[V, m\ s^{-1}] = 5913.37\ [1 - (11.048 / [d, mm])]$
LLSQ Coefficient of Determination = 0.9680
$[V, m\ s^{-1}]^2 = (5641.77)^2\ [1 - (35.254 / [d, mm])^2]$
LLSQ Coefficient of Determination = 0.9833

PBXN-111 : Unconfined Charges, Charge Diameters: 38.7 mm to 69.1 mm
Critical diameter: 37.6 ± 1.6 mm
$[V, m\ s^{-1}] = 6193.4\ [1 - (6.849 / [d, mm])]$
LLSQ Coefficient of Determination = 0.9076
$[V, m\ s^{-1}]^2 = (5760.0)^2\ [1 - (18.325 / [d, mm])^2]$
LLSQ Coefficient of Determination = 0.9364

Composition H-6: Unconfined Charges, Charge Diameters 9.4 mm to 38 mm.
Critical diameter: < 7 mm
$[V, m\ s^{-1}] = 7431.4\ [1 - (0.284 / [d, mm])]$
LLSQ Coefficient of Determination = 0.7873
$[V, m\ s^{-1}]^2 = (7368.3)^2\ [1 - (2.023 / [d, mm])^2]$
LLSQ Coefficient of Determination = 0.8330
Calculated Critical Diameter = 4.4 mm (based on Reference 1)

Composition B: Unconfined Cylindrical Charges, Charge Diameters 5.6 to 25.5 mm.
Critical diameter: 4.3 mm
$[V, m\ s^{-1}] = 7955.1\ [1 - (0.2394 / [d, mm])]$
LLSQ Coefficient of Determination = 0.9533
$[V, m\ s^{-1}]^2 = (7879.0)^2\ [1 - (1.541 / [d, mm])^2]$
LLSQ Coefficient of Determination = 0.9807.
Calculated Critical Diameter = 3.4 mm (based on Reference 1)

4. Discussion

Using standard spreadsheet techniques, one can readily see that over a large range of diameters, the experimental data for the RDX-driven component of the overall detonation reactions [1, 2, 13] of PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B fit Eq. 2 rather more satisfactorily than Eq. 1. This becomes more apparent if one plots the same relationships using averaged V of D data for a particular value of d.

The significance of the results for PBXW-115 (Aust.) and PBXN-111 has already been discussed [2] . In as far as Composition B and Composition H-6 are concerned, Composition H-6 can be regarded as an aluminised form of Composition B. However, from the results presented in Table 5 and summarised in Table 6, one can see both that the experimentally-determined limiting values of the detonation velocity at infinite charge diameter and the (elliptical) reaction zone length parameter, described by D* and a* from Eq. 2, are different for these two compositions, reflecting the modifying role of aluminium in the RDX-driven detonation reaction in Composition H-6 at these charge diameters. The reaction zone length parameter in Composition B is more compact or more condensed [2, 5] than that in Composition H-6, but not greatly so; on the other hand, the value of D*, the limiting value of the velocity of detonation at infinite charge diameter, for Composition B is much greater than that of Composition H-6. While, overall, there are much more exothermic reactions taking place in Composition H-6 [Table 7, calculated from a program developed by Cichra and Doherty [14] based on thermochemical inputs and the Kamlet-Jacobs methodology], the reactions in Composition B are generating more energy at the detonation front and depositing more energy before the CJ-plane, in the charge sizes under investigation here [13, 15, 16].

Table 6. The Limiting Value of the Velocity of Detonation and the Reaction Zone Length Parameters in PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B, calculated from Eq. 2.

Formulation	D*, m s^{-1}	a*, mm
PBXW-115 (Aust.)	5642	35.3
PBXN-111	5760	18.4
Composition H-6	7368	2.02
Composition B	7879	1.54

Table 7. The Calculated Heats of Detonation for Composition B and Composition H-6, for Possible Reaction Pathways, following Cichra and Doherty [14].

Formulation	**Calculated Heat of Detonation (kJ / kg)**			
	Reaction Pathway, as defined by Cichra and Doherty [14]			
	MO - CO - CO_2 - H_2O	MO - CO - H_2O - CO_2	MO - H_2O - CO - CO_2	CO - MO - MN
	(where MO = Al_2O_3 and MN = AlN, where applicable)			
Comp. B	3930	3700	4690	not applicable
Comp. H-6	7700	7700	8530	4155
Compare:				
RDX	5600	5050	5050	not applicable
	RDX: ρ 1.80 Mg m^{-3}, V(∞) 8700 m s^{-1}			
PBXW-115	7725	7725	8550	6250
	PBXW-115: ρ 1.80 Mg m^{-3}, V(∞) 5642 m s^{-1}			
TNT	(Ref. 12, 14), ρ 1.64 Mg m^{-3}, V(∞) 6900 m s^{-1}			
	Δ H (exptl.) 4500 kJ / kg			
	Products: principally H_2O, CO, CO_2, N_2, $C_{(s)}$ [Ref. 15]			
	2650	2650	4100	not applicable

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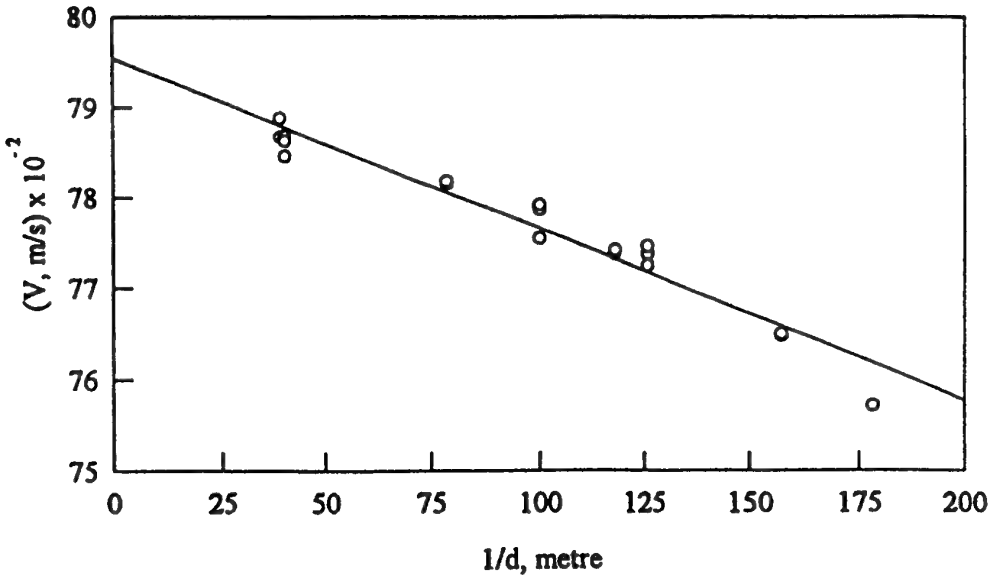

Fig.1 The plot of (V of D) vs (1/d) for unconfined charges (cylindrical) of Composition B.

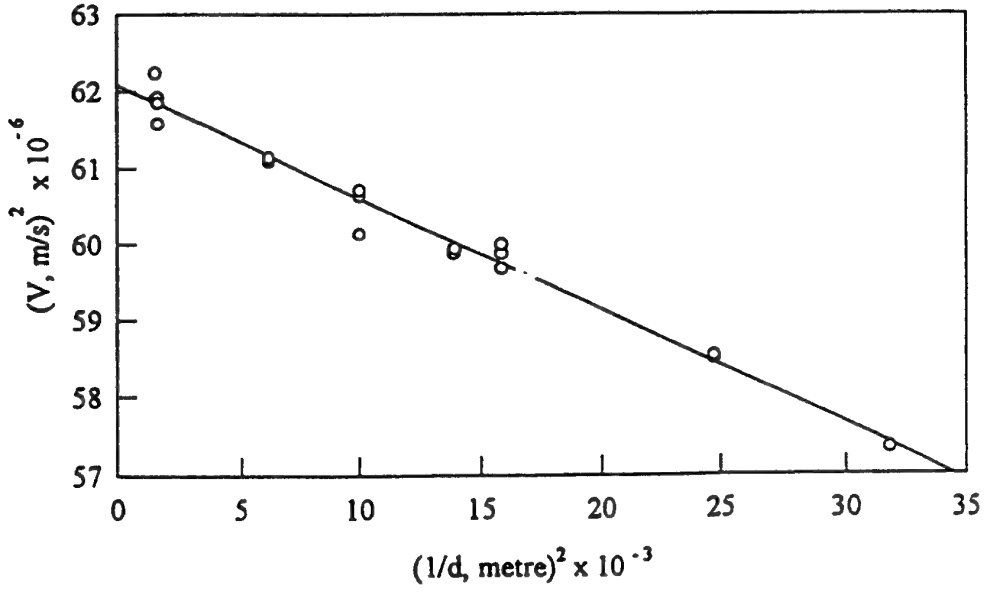

Fig. 2. The plot of $(V \text{ of } D)^2$ vs $(1/d)^2$ for unconfined charges (cylindrical) of Composition B.

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No limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

Insensitive Munitions; Explosives; PBX; Polymer Bonded Explosives; PBXW-115; PBXN-111; High Explosives; Composition B; Composition H-6; Velocity of Detonation; Reaction Zone

19. ABSTRACT

Experimental data on the dependence of velocity of detonation on charge diameter, V(d), of unconfined cylindrical charges of the underwater explosives, PBXW-115 (Aust.), PBXN-111 and Composition H-6, and of Composition B, the explosive charge fill offered by Nordic Defence Industries for the Danish Mine Disposal Charge, Damdic, are given. These data are analysed in terms of the previously-reported empirical relationship between the V(d), the detonation velocity at infinite charge diameter (D*) and the reaction zone length parameter, (a*).